Stellar Imager

From DUcollab

Contents

Introduction

The Stellar Imager (SI) is one of NASA's "Vision Missions" - concepts for future, space-based, strategic missions that could enormously increase our capabilities for observing the Cosmos. SI is designed as a UV/Optical Interferometer which will enable 0.1 milli-arcsecond (mas) spectral imaging of stellar surfaces and, via asteroseismology, stellar interiors and of the Universe in general. The ultra-sharp images of the Stellar Imager will revolutionize our view of many dynamic astrophysical processes by transforming point sources into extended sources, and snapshots into evolving views. SI, with a characteristic angular resolution of 0.1 milli-arcseconds at 2000 Å, represents an advance in image detail of several hundred times over that provided by the Hubble Space Telescope. The Stellar Imager will zoom in on what today - with few exceptions - we only know as point sources, revealing processes never before seen, thus providing a tool as fundamental to astrophysics as the microscope is to the study of life on Earth. SI's science focuses on the role of magnetism in the Universe, particularly on magnetic activity on the surfaces of stars like the Sun. It's prime goal is to enable long-term forecasting of solar activity and the space weather that it drives, in support of the Living With a Star program in the Exploration Era. SI will also revolutionize our understanding of the formation of planetary systems, of the habitability and climatology of distant planets, and of many magneto-hydrodynamically controlled processes in the Universe. Stellar Imager is included as a "Flagship and Landmark Discovery Mission" in the 2005 Sun Solar System Connection (SSSC) Roadmap and as a candidate for a "Pathways to Life Observatory" in the Exploration of the Universe Division (EUD) Roadmap (May, 2005) and as such is a candidate mission for the 2025-2030 timeframe. An artist's drawing of the current "baseline" concept for SI is shown below in Figure 1.
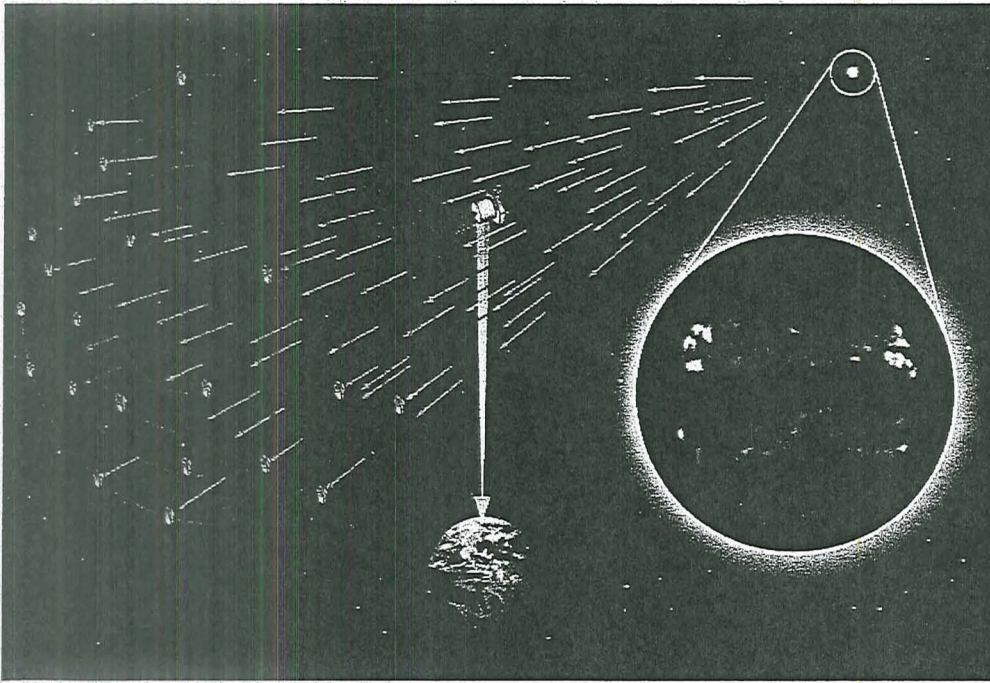
Figure 1: An artist's concept of the baseline SI design, a Fizeau Interferometer with 20-30 one-meter primary mirrors, which are mounted on formation-flying "mirrorsats" distributed over a parabolic virtual surface whose diameter can be varied from 100 m up to as much as 1000 m, depending on the angular size of the target to be observed. The individual mirrors are fabricated as ultra-smooth, UV-quality flats and are actuated to produce the extremely gentle curvature needed to focus light on the beam-combining hub that is located from 1 – 10 km distant. The focal length scales linearly with the diameter of the primary array: a 100 m diameter array corresponds to a focal length of 1 km and a 1000 m array with a focal length of 10 km. (Courtesy: K. Carpenter/NASA)

Science Goals

Most of us rarely give the Sun a second thought. We do not question its presence or its apparent stability as we see it traverse the sky every day. The Sun is, however, a variable star. Its variability affects society by modulating Earth's climate. It also affects our technology, upon which we are becoming ever more reliant: eruptions on the Sun disrupt communications; affect navigation systems; cause radiation harmful to astronauts exploring beyond the Earth's atmosphere and to airline passengers traveling through it; and occasionally push power grids to fail. The cause of this variability is the Sun's magnetic field. This intangible and unfamiliar fundamental force of nature is created in the convective envelope of the Sun by a process that we call the dynamo. The Stellar Imager will help us understand the dynamo process in the Sun by observing magnetic processes in Sun-like stars and in other astrophysical systems. That insight into solar activity will help us mitigate the effects of space weather, both on Earth and beyond.

Historical records show that the Sun can change its activity significantly; both upward and downward (see Figure 2 below). Activity decreased, for example, for multiple decades during the 17th Century when Earth experienced the Little Ice Age. A sustained increase in activity – such as happened during the medieval Grand Maximum – may cause a warm spell, and will be associated with an increase in the frequency of space storms, and in the ultraviolet radiation that is harmful to life on Earth. The dynamo is one of the truly large mysteries in astrophysics. There is at present no model for a stellar dynamo that can be used to forecast the Sun's activity on the time scale of months to decades. We know that the solar dynamo operates throughout the outermost 200,000 km of the solar interior, in and just below the convective envelope. The vastness of this volume relative to the smallest relevant scales precludes a complete numerical model. There is not even a generally accepted approximate dynamo model. In fact, the experts do not agree where most of the dynamo action occurs within the stellar interior, or which are the key processes that are involved.
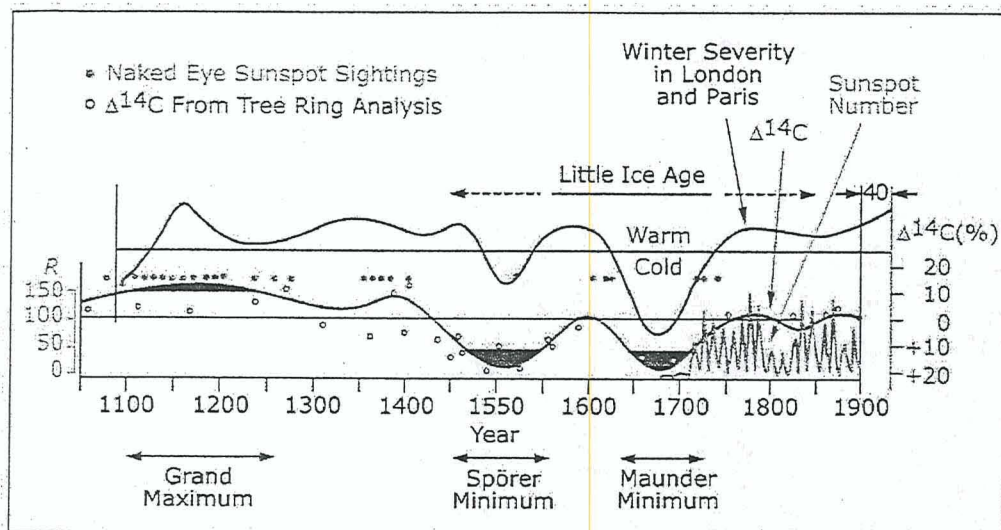
Figure 2: Solar activity and Earth's climate: the nature of the link is yet to be understood, but the correlation suggests that solar activity somehow couples into the Earth's climate system. (From the Living With A Star initiative)

What makes understanding the solar dynamo so difficult? That answer involves two of the major developments of science in the 20th century: a stellar dynamo involves both non-linear and non-local effects. Such a dynamo can exhibit fundamentally different properties even for relatively small changes in the processes involved. In other words: if a dynamo model does not incorporate all relevant physics in sufficient detail, it will not enable us to predict solar activity on time scales of years or more, or to understand its gross characteristics in the distant past and future. In order to develop a dynamo model with predictive value, we must establish which processes are involved, and which approximations are allowed. It would take hundreds of years to validate a dynamo model for the Sun using only observations of the Sun, given its irregular 11-year magnetic heartbeat and the significant overlying long-term modulations. The more efficient alternative is to test and validate dynamo models using Stellar Imager observations of the variable magnetic activity of a broad sample of stars. Indeed, surface magnetic activity records of stars on or near the lower main sequence show variability similar to the Solar variability, including Maunder minimum-like phases, on time scales of many decades.

Key to successfully navigating the route to a workable, predictive dynamo model is the realization that in order to understand the solar dynamo, we need a population study: we need to study the dynamo-driven activity in a sample of stars like the Sun, and compare it to observations of young stars, old stars, binary stars, etc. The potential for a breakthrough in our understanding and our prediction ability lies in spatially-resolved imaging of the dynamo-driven activity patterns on a variety of stars. These patterns, and how they depend on stellar properties (including convection, differential rotation and meridional circulation, evolutionary stage/age), are crucial for dynamo theorists to explore the sensitive dependences on many poorly known parameters, to investigate bifurcations in a nonlinear 3-dimensional dynamo theory, and to validate the ultimate model.

Direct, interferometric imaging – the goal of the Stellar Imager - is the only way to obtain adequate information on the dynamo patterns for stars of Sun-like activity. Alternative methods that may offer limited information on spatial patterns on much more active stars fail for a Sun-like star:

- rotationally-induced Doppler shifts in such stars are too small compared to the line width to allow Zeeman-Doppler imaging
- the activity level is insufficient to lead to significant spectral changes associated with magnetic line splitting
- rotational modulation measurements are inherently subject to deconvolution limitations that leave substantial ambiguities in the latitude distributions, locations and sizes of spots, and cannot be used to understand the facular contributions in quiet regions that are governed by field dispersal and differential rotation.

The direct imaging by SI of stellar activity will sidestep these problems. Equally importantly, the asteroseismic observations planned with SI will determine the internal properties of stellar structure and rotation, thus directly providing

crucial information relevant to the physical operation of the dynamo mechanism. Imaging magnetically active stars and their surroundings will also provide us with an indirect view of the Sun through time, from its formation in a molecular cloud, through its phase of decaying activity, to its ultimate death beyond the red-giant phase during which the Sun will swell to about the size of the Earth's orbit (see Figure 3).
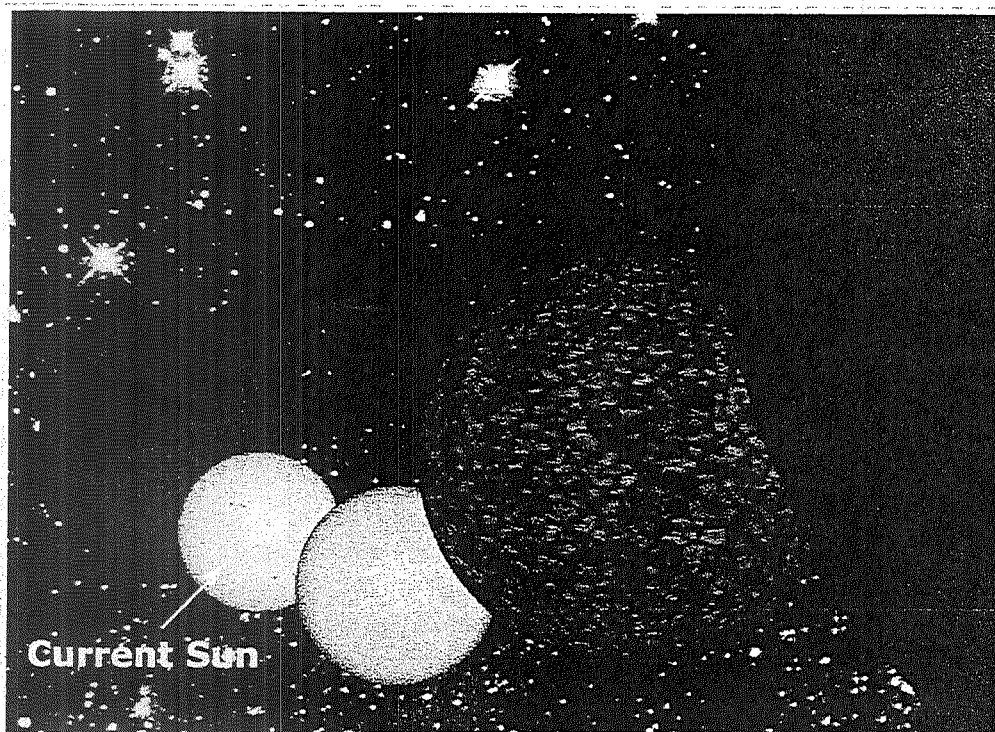

Figure 3: The evolution of the Sun over a period of 10 billion years, from a proto-stellar disk to a red giant star. Magnetic activity plays a role from the formation of the star and its planetary system through most of its main-sequence life. (Courtesy: K. Schrjver/LMATC)

A long-baseline interferometer in space will also benefit many fields of astrophysics. Imagine, for example, unprecedented images of active galactic nuclei, quasi-stellar objects, supernovae, interacting binary stars, supergiant stars, hot main-sequence stars, star-forming regions, and protoplanetary disks. Figure 4 shows simulated SI results, assuming 30 mirror elements distributed in a non-redundant pattern with the indicated maximum baselines. SI will produce images with hundreds of times more detail than the Hubble Space Telescope (HST), which in turn will bring the study of dynamical evolution of many astrophysical objects into reach: hours to weeks between successive images will detect dramatic changes in many objects, e.g., mass transfer in binaries, pulsation-driven surface brightness variation and convective cell structure in giants and supergiants, jet formation and propagation in young planetary systems, reverberating active galactic nuclei, and many others.
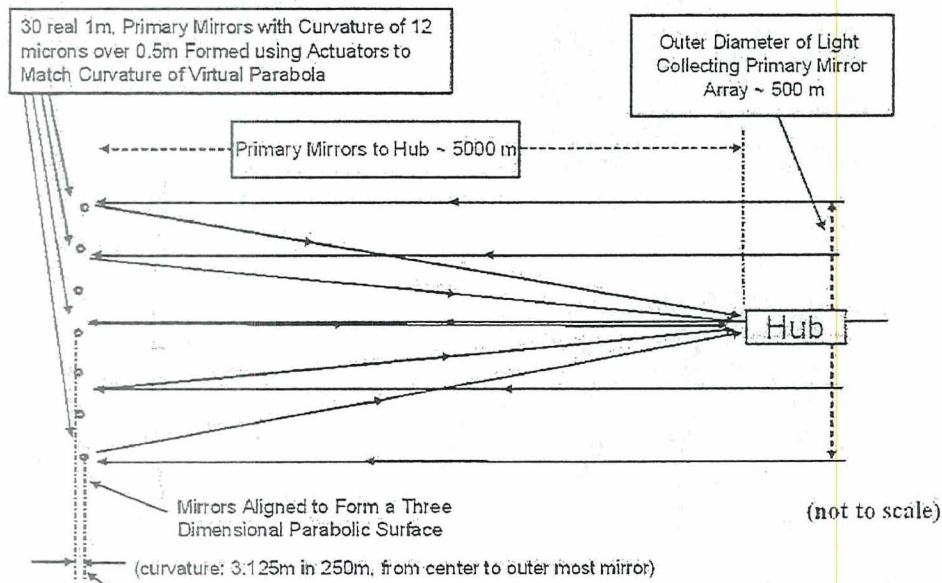
What Will Stellar Imager See?
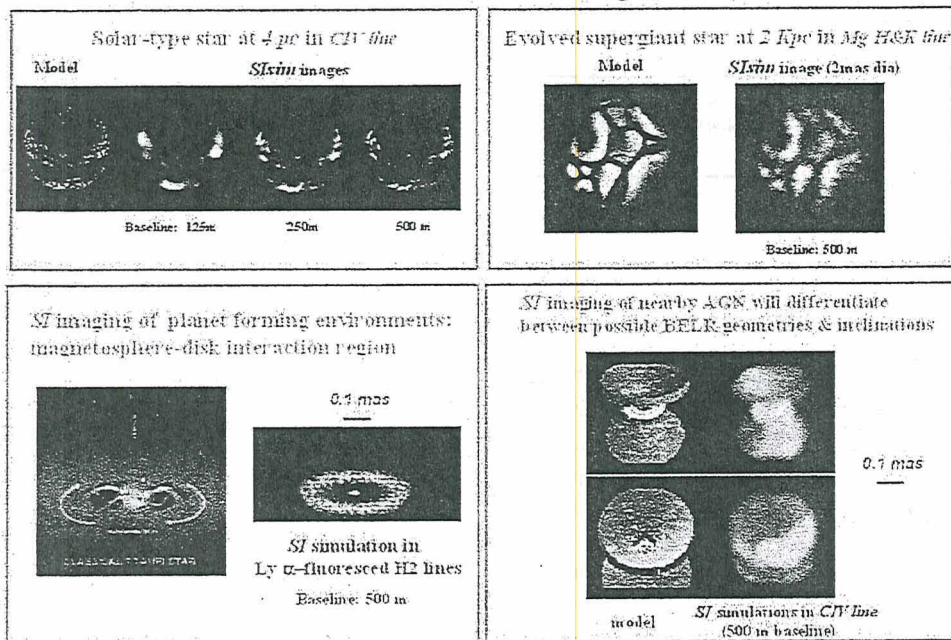
Figure 4: Simulations of the ability of SI to observe various astronomical objects in ultraviolet light at very high spatial resolution. (Courtesy: K. Carpenter/NASA)

Mission Architecture

The current baseline architecture concept (see Figures 1 and 5) for the full Stellar Imager (SI) mission is a space-based, UV-Optical Fizeau Interferometer with 20-30 one-meter primary mirrors, mounted on formation-flying "mirrorsats" distributed over a parabolic virtual surface whose diameter can be varied from 100 m up to as much as 1000 m, depending on the angular size of the target to be observed. The individual mirrors are fabricated as ultra-smooth, UV-quality flats and are actuated to produce the extremely gentle curvature needed to focus light on the beam-combining hub that is located at the prime focus from 1 – 10 km distant. The focal-length scales linearly with the diameter of the primary array: a 100 m diameter array corresponds to a focal length of 1 km and a 1000 m array with a focal length of 10 km. The hub and all of the mirrorsats are free-flyers in a tightly-controlled formation in a Lissajous orbit around the Sun-Earth L2 point. A second hub is strongly recommended to provide critical-path redundancy and major observing efficiency enhancements. The observatory may also include a "reference craft" to perform metrology on the formation, depending on which metrology design option is chosen.

SI Cross-Sectional Schematic

30 real 1m, Primary Mirrors with Curvature of 12 microns over 0.5m Formed using Actuators to Match Curvature of Virtual Parabola

Outer Diameter of Light Collecting Primary Mirror Array ~ 500 m

Primary Mirrors to Hub ~ 5000 m

Hub

Mirrors Aligned to Form a Three Dimensional Parabolic Surface

(not to scale)

(curvature: 3.125m in 250m, from center to outer most mirror)

March 15, 2005   The Stellar Imager Vision Mission   4

Figure 5: An overview of the SI design, in cross-section. (Courtesy: K. Carpenter/NASA)

Further Information

Additional information on SI and related technology development can be found at URL: http://hires.gsfc.nasa.gov/si/.

Please see the separate DU/EoC entry on Interferometry from Space for more general information on this topic and for information on other space-based, interferometric mission concepts.

Workspace Main Page

Article initiated by Ken Carpenter

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